Preliminary

Elastic and Shrinkage Deformation of the Cell Wall in the Longitudinal Direction*[1]

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It has been suggested that the elastic deformation of wood is closely related to it's shrinkage deformation. However, there are few reports which dealt with this problem. In this report, the relationship between the Young's modulus and the shrinkage of wood in the longitudinal direction was investigated.

Almost all cells of coniferous wood are tracheids. Therefore, using parallel multilayer model composed of the cell wall and air, the longitudinal Young's modulus (E) of coniferous wood, as first approximation, can be expressed by the following law of mixtures.

$$E=\Sigma(\delta_{wi}E_{wi}+\delta_{ai}E_{ai})\cong\Sigma\,\delta_{wi}E_{wi}$$
$$\Sigma(\delta_{wi}+\delta_{ai})=1$$

where E_{wi} and δ_{wi} are the Young's modulus and the volume fraction of the i-th wall layer, while E_{ai} ($\cong 0$) and δ_{ai} are those of the i-th air layer. Specific gravity (γ) is given by $\gamma=\Sigma\,\delta_{wi}\gamma_{wi}$, where γ_{wi} is the specific gravity of the i-th wall layer. When the mean specific gravity (γ_{wi}) and the mean Young's modulus of the cell wall (E_w) are defined by $\gamma/\Sigma\delta_{wi}$ and $\Sigma\delta_{wi}E_{wi}/\Sigma\delta_{wi}$, respectively, E_w is given by

$$E_w=E(\gamma_w/\gamma). \tag{1}$$

γ_w can be regarded as a constant value of 1.45 in the oven dry condition irrespective of wood species, so that the specific Young's modulus (E/γ) is proportional to E_w.

In the same way, when the longitudinal shrinkage from the wet condition to the oven dry condition of the i-th wall layer is denoted by S_{wi} and the mean longitudinal shrinkage of the cell wall (S_w) is defined by $\Sigma\delta_{wi}S_{wi}/\delta_{wi}$, the shrinkage of wood (S) corresponds to S_w.

These results indicated that E/γ, instead of E, should be related to S to examine the relationship between E_w and S_w in the longitudinal direction.

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In this experiment, normal and compression woods of five species, namely: Sugi *(Cryptomeria japonica)*, Hinoki *(Chamaecyparis obtusa)*, Sitka spruce *(Picea sitchensis)*, Agathis *(Agathis bornensis)*, and Igem *(Podocarpus imbricatus)*, were used. The size of the specimens was 5 mm (radial) by 5 mm (tangential) by 100 mm (longitudinal). Three hundred specimens were used. A three-point bending test was conducted to obtain E in the oven dry condition. S was determined from the dimensional changes of the specimens from the wet condition to the oven dry condition.

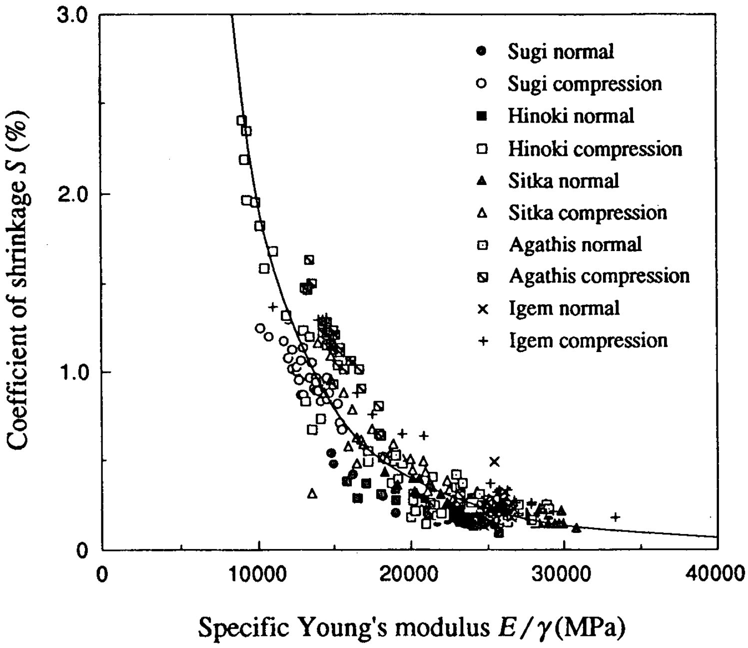

Fig. 1. Relationship between E/γ and S in the longitudunal direction. The solid line shows the correlative equation for 300 specimens.

Fig. 1 shows the relationship between E/γ(MPa) and S(%). There was a good correlation between them, yielding the following expression.

$$S=\frac{\mathrm{b}}{(E/\gamma)^{a}}, \quad (\mathrm{R}^2=0.819) \tag{2}$$

where $a=2.40$ and $b=8.18\times 10^9$. The experimental values of the normal wood samples have larger E/γ and smaller S, whereas those of the compression wood samples have smaller E/γ and larger S. The mean microfibril angle (θ) greatly contributes to both E/γ and S in the longitudinal direction[1,2]. Therefore, it is considered that E_w is closely related to S_w through θ.

The following expression between E_w and θ is proposed[1].

$$E_w(\theta)=\frac{E_0}{1+k\theta^2} \tag{3}$$

where E_0 is the Young's modulus of the cell wall at $\theta=0$, k is a factor which depends on both

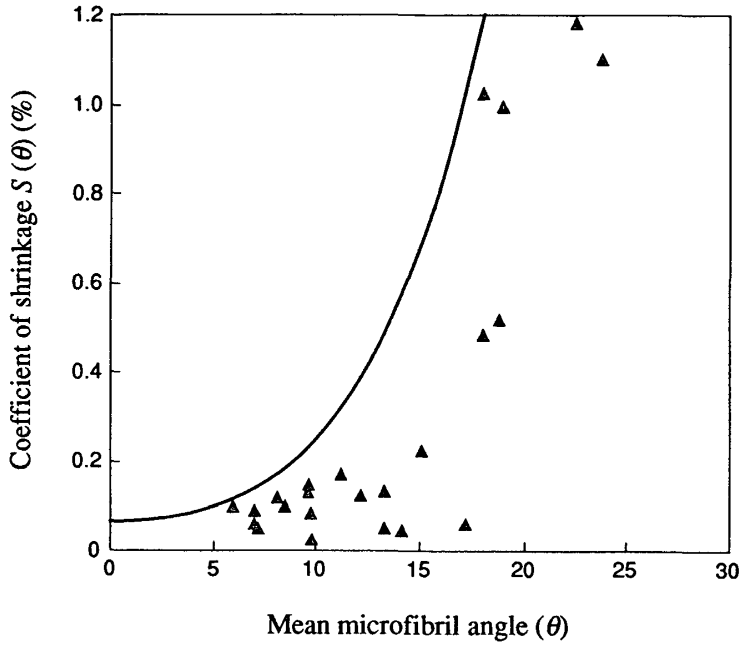

Fig. 2. Comparison between the calculated (solid line) and experimental (▲) values of $S(\theta)$.

temperature and moisture content. Combining (1), (2), and (3) gives

$$S(\theta)=S_0(1+k\theta^2)^a \tag{4}$$

where $S_0=b(\gamma_w/E_0)^a$ is the shrinkage at $\theta=0$. The values of S_0 and k were 0.0638 and 0.00735, respectively. In Fig. 2, the calculated values, shown by a solid line, are compared to the experimental values[2].

References

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